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School of Engineering

Final Scientific Report*

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Submitted by

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Momentum Distribution of Ions in a Plasma Beam

Summary

This report describes a modified time of flight analyzer that was used to measure the velocity distribution function of the ions in a dense plasma beam. The beam is produced with a coaxial gun of the Cheng type.

The beam density is approximately $10^{17}/cm^3$, and the ions have an average directed velocity of 800 eV. The ions are cold while the electrons have a temperature of 40 eV. The density and energy of the ions in the beam are suitable for injection in a Shiva machine.

The work reported here was done by A.M. Ferendeci, O.K. Mawardi, Robert Webster and Paul Elkman.

I. Introduction

An exploding wire (actually, a foil) provides the initial dense plasma that is used in the SHIVA plasma compression.(1) The disadvantage of this source of plasma is that it is self-destructive. A great deal of preparation is thus needed prior to repeating a plasma compression experiment.

The substitution of the "liner" material with an injected plasma shell presents definite advantages. Indeed, the source is not self-destructive, the initial density, temperature and Z number of the ions can be selected with a certain latitude. Furthermore, the initial mean velocity of the ions may add to the dynamic stability of the subsequent imploding pinch.

But it is well known that the sideways spreading of a plasma beam irrespective of its geometry (cylindrical shell of collimated beam) depends on the ratio of the thermal velocity to the mean directed velocity of the ions. If the beam is cold, i.e., the collection of ions are almost monoenergetic, then the beam spatial spreading is very small. The latter condition is a desirable criterion because a coaxial shell of monoenergetic particles would lead to plasma sheets of uniform thickness.

Very little information, however, is available on the actual distribution of the particle velocities in beams produced by plasma guns. In several experiments by Marshall and others[2] the average directed velocity of the particles have been measured. On the other hand, no information is available for their velocity distribution. This report describes the work that was accomplished at the Plasma Research Laboratory of Case Western Reserve University to estimate the velocity distribution function of the ions in the plasma.

II. Background Considerations

There are several well known methods that can be used to measure the momentum distribution of ions.[3] It is advisable, however, to select a procedure that does not alter the plasma parameters. An added complication to the configuration that we used was contributed by the presence of a metallic slit inserted in the path of the beam. This obstacle not only cooled down the plasma but in addition, increased the density through the entrainement of ablated material by the beam.

We can readily show that the use of a drift tube that will lead to a spatial separation of the ions and subsequently allow one to infer the velocity distribution from time of flight (TOF) measurements cannot be applied in this case. The proof goes this way.

In the analyzer shown in Figure 1 the ions traversing the slit opening are deflected by the magnetic field while the electrons are reflected back.

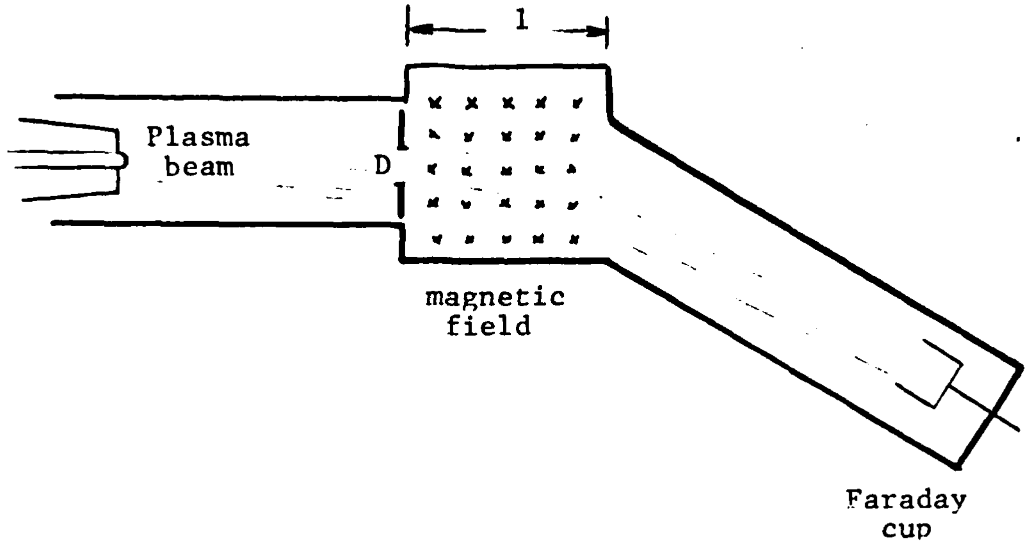

Figure 1. Suggested analyzer for measurement of velocity distribution. The slit is maintained at a negative potential. A magnetic field is applied at right angles to the beam.

In order for the separation of electrons from the ions to take place it is essential that the plasma behave in a collosionless fashion. Consequently one must have $\lambda_{ei} \gg \lambda_D$ and $\lambda_{ei} \gg D$ (the slit opening) where λ_{ei} stands for the mean free path for electron-ion collisions and λ_D is the Debye length.

The plasma state in a typical beam used is as follows

$$n_e = 10^{17}/cm^3; \qquad T_e = 40\ eV$$

and the ion directed velocity v_i = 800 eV (20 cm/μsec). This reflects as $\lambda_{ei} \approx 2.15 \times 10^{-2}$ cms, $\lambda_D = 1.49 \times 10^{-5}$ cm, and $D \approx 0.5$ cm. Wheras the first condition is satisfied, the second is violated.

As a result, the beam after emerging from the slit will consist of a mixture of ions and electrons. Now as the plasma traverses the magnetic field region ℓ, (assume for the sake of discussion $\ell = 10$ cm), the ions could be separated from the electrons. For this to occur the ion transit time τ in the magnetic region ($\tau = \ell/v_i = 0.5$ μsec) should be smaller than the electron equibration time i.e. $\tau \ll \tau_{ei}$. For the plasma parameters near the gun, this condition cannot be fulfilled.

In general, TOF spectroscopy can be applied to the plasma and with the use of computers the final extraction of the velocity distribution should pose no problems. TOF analysis is accomplished by "chopping" the sampled beam and thus measuring the change in the density distribution as these chopped bursts travel down the flight tube.

This approach was considered promising and in this report an account of our investigations is described below.

III. Theory of Modified TOF Analyzer

The conventional TOF analyzer requires the ability to separate the ions from the electrons prior to their reaching the detectors. But we saw in the discussion mentioned above that the plasma in collision dominated and hence the separation of charges is not easily achieved.

To circumviate this difficulty (of charge separation) a modified TOF analyzer was developped and which was based on a procedure used with some success in molecular beam work. To fix the ideas this known procedure is briefly described. The arrangement for a typical TOF analyzer used in molecular beam work is shown in Figure 2.

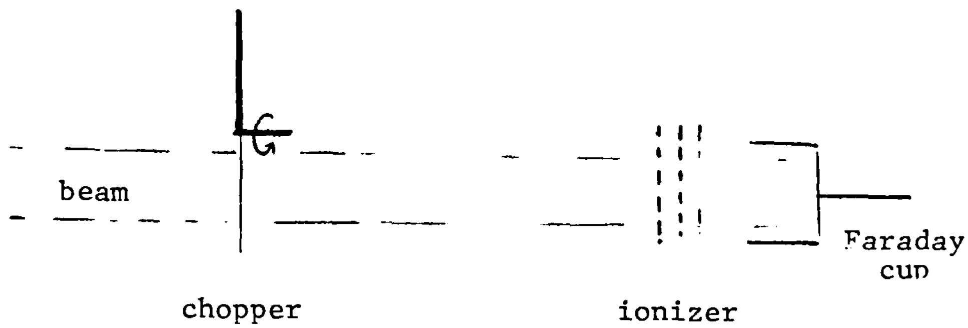

Figure 2 TOF Analyzer layout.

In this analyzer the beam in interrupted periodically by a mechanical chopper as shown above. The chopped beam travels down the flight tube, is ionized, the electrons are removed and the ions are collected by a Faraday cup.

The signal $I^+(t)$ from the detector is expressed by (taken from Reference 4):

$$I^+(t) = K \int_0^t g_d\ (t - \lambda) \int_0^\lambda s^2 f(s)(\gamma/L)A(\tau)\,d\tau\,d\lambda \tag{1}$$

where $A(\tau)$ is the gate function, L is the TOF distance, γ is the most probable velocity, $s(=v/\gamma=L/\gamma(\lambda-\tau)$, where v is the ion speed) is the velocity ratio, $g_d(t)$ is the dynamic function of the detector and its electronics, K is the detector calibration constant and f(s) is the velocity distribution function of the ions.

The function f(s) is uncoupled from this doubly convoluted integral and it can be shown to be given by

$$F(t) = \int_0^t \mathcal{L}^{-1} \left[\frac{1}{A(t-\tau)}\right] E(\tau)\tau d\tau \qquad (2)$$

where $F(t) = s^2 f(s)$ and

$$E(t) = \frac{L}{\gamma K} I^+(t) + \tau_e \frac{d}{dt} I^+(t) \qquad (3)$$

since E(t) can be computed from the detected TOF signal Eq. 2, it is seen that F(t) (and hence f(s)) can be deduced once the Laplace transforms of the gate function A(t) and its inverse are performed.

The beauty of this procedure is that the distribution function of the ions in the beam can be deduced from the detector signal.

To adapt this concept to our case in order to cope with the fact that the ions will not be separated from the electrons, we measure the temporal dependence of the electron density at two different points along the beam. Let these two dependencies by $n_1(t - \tau)$ and $n_2(t)$ where

τ is the time of flight for ions.

We now consider n_1 to be the gate function and n_2 to be the detected signal of Eq.2 and 3. Using the procedure of Ref.(4) it is then possible to deduce the velocity distribution function of the electrons. If one assumes charge neutrality in the beam one could approximately obtain the velocity distribution of the ions from the measurement of electron densities. This congruent agrument applies if the ions and electrons are at the same temperature.

When this is not the case, one should measure the temporal dependence of the ion density at two points and follow the same line of arguments. Of course, one method of deleting ion density is by observing a specific line radiation.

IV. Experimental Procedure

Since the beam in our case is highly energetic a mechanical chopper will not do. Fortunately, the fact that the beam is generated from a transient discharge, an effective chopping of the beam is automatically obtained.

Figure 3 shows the modified time of flight experiment we have performed. Figure 3a shows the two laser interferometers which measure the temporal electron density variations at two points along the beam. The first interferometer signal is now the "chopper" function A is Eq.1, and the second signal is the final detector output. One now has to solve the integral equations through use of computers to find the ion-velocity distribution. One can immediately observe the directed velocity of the beam from the delay between the two signals. By varying the distance L separating the two interferometers one can also infer the change in the ion distribution function as the beam moves along the plasma chamber. Interferometer type measurements are also useful in evaluating the radial density profiles as well as variations of the distribution function in the radial direction. These are achieved usually through the use of proper Abel inversion procedures.

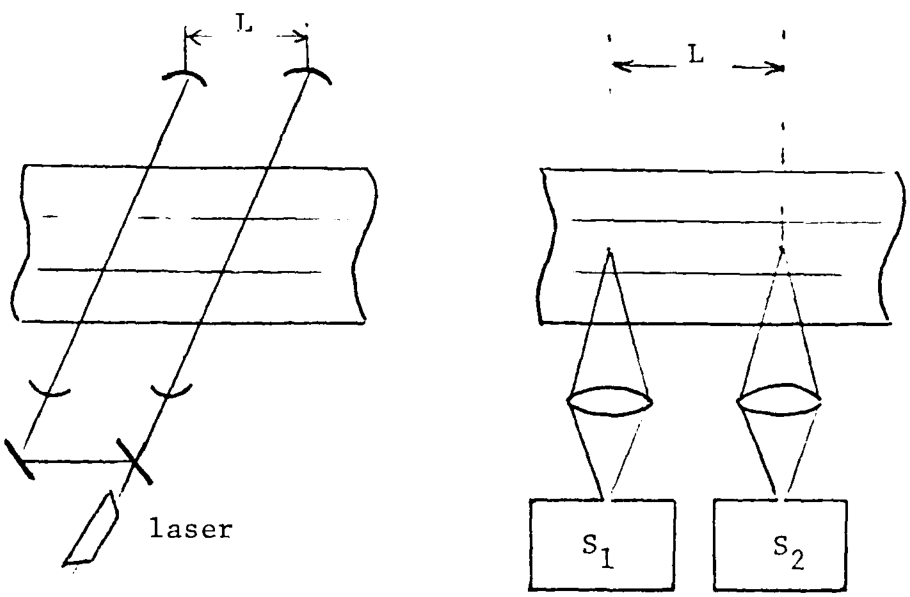

Figure 3 Modified time of flight spectroscopy. a) the laser interferometer. b) line radiation. L is the distance between the two observation points.

The laser interferometer measures the electron density of the plasma beam. One assumes macroscopic charge neutrality of the beam. Although electrons are moving at the same directed velocity as the ions the questions of ions having the same velocity distribution as the electrons is questionable. In order to clarify this point and at the same time obtain an independent measurement of the ion velocity distribution, one can pick certain line radiations from the plasma that are sensitive to the ion density, observe any of these lines at two different points separated by a distance L and apply the calculational procedures of the TOF spectroscopy.

One of the main conclusions that will be derived from the time of flight spectroscopy measurements will be the observation of the variations of the ion velocity distribution as the beam moves away from the plasma gun. The change in the ion velocity distribution will be corelated with the electron distribution function to find out the collisional effects between the ions and electrons.

V. Results

To apply the modified time of flight analysis on the plasma beam, a plasma gun[5] with short electrodes ($\approx$20cm) were assembled with appropriate capicitor banks and electronics. A He-Ne laser beam was split into two parallel beams and two Michelson interferometers were set-up as shown in Figure 3a. For these interferometers proper coupling ports at Brewster angles were added to the plasma chamber. The detector outputs were connected to a dual beam oscilloscope. At the same time, to run a simultaneous experiment with line radiation, two portions of the plasma beam, separated by a distance L were projected on to two separate spectrometers with elaborate mirror arrangements. Photomultiplier outputs placed at the exit slits of the spectrometers were connected to a second dual beam oscilloscope. Triggering of the detecting systems were accomplished by optical fibers.

Each interferometer was tested separately and outputs from the individual photomultiplier were detected, but due to noise problems, synchronization of the detecting system as a whole was not established at the time this report is written. The system is at the stage where measurements will be resumed once the electric noise problems are taken care of.

References

1. J.H. Degnan et al., "On forming cylindrical gas shells in electrode gaps for electromagnetic implosion generation", Tech. Report AFWL-TR-73-265(1976); P.J. Turchi & Wil. Baker J. Appl. Phys. 44, 4936 (1973).

2. J. Marshall, Phys. Fluids 3, 135 (1960).
   K. Halbach et al., Phys. Fluids, 7, S44, (1964).
   M. Wolf and O.K. Mawardi, Bull. Am. Phys. Soc. 18, 1367, (1973).

3. H.S.W. Massey and E.H.S. Burhop, Electronic and Ionic Impact Phenomena, (Clarendon Press, Oxford) 1956.

4. W.S. Young, "Extraction of the speed distribution function from a time-of-flight signal," J. Appl. Phys. 46, 3888 (Sept. 1975).

5. "Theory and construction of time resolved x-ray spectometer," O.K. Mawardi, C. Speck, R. Vesel, A.M. Ferendeci, Final Technical Report, AFOSR-75-2806, August, 1978.

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